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Art. VI.—*Notes on an Occurrence of Quartz in Basalt.*

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(Communicated by Professor E. W. Skeats).

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I.—Introductory.

My attention was first directed towards occurrences of quartz in basalt by noting, some four years ago, the abundance of angular quartz fragments that are to be found over the basaltic plains which stretch to the southward from Mt. Greenock, a volcanic hill in Central Victoria.

Following this up, it was found that at a spot on McCallum's Creek, where the stream has cut through to the Ordovician bedrock, the cliffs on the left bank showed a remarkable exposure of quartz in the basalt. Since then, the occurrence of quartz, sparsely, in our basalts has been found so common, that attention has been given, as far as the literature was accessible, to similar or related occurrences in other parts of the world. While results in the Mt. Greenock area are somewhat disappointing, they are certainly not without interest.

II.—Description of the Mt. Greenock area.

As will be seen by the small sketch map (Fig. 1), copied from that published by the Geological Survey of Victoria, the geology of the area is simple. East and west of the basalt flow, low timbered ordovician ranges occur; the ordovician slates are traversed by innumerable quartz veins.

The deep lead gravels which were buried by the basalt were wide, and, in places, up to 30 feet thick; the basalt sheet averaged about 100 feet in thickness. The eastern drainage is now carried off by McCallum's Creek to the Loddon River, and the eastern edge of the basalt has been much more vigorously dissected than the western. The buried gravels were highly auriferous, and have been extensively mined for practically their full length.

The mount itself is a volcanic cone, built of scoriaceous material, and with a well-preserved breached crater, the breach being to the north-west. It cannot be said for certain that the lava in the southern part of the area came from Mount Greenock; it may be from Mt. Mitchell, some four miles further south. The probability is, however, that it is mainly from Mount Greenock.

Fig. 1. Sketch map of the Mount Greenock area. A and B are specially referred to in the text. The cycles represent mines following the buried leads.

III.—Previous mention in literature.

Since the commencement of investigations into this occurrence, two prior references to it have been found; the exact places referred to are not known, but there are several places where the abundance of quartz is striking.

(a) Major Mitchell, who ascended and named Mt. Greenock in the year 1836, records in the "Journal" of his explorations, that on September 25th, when nearing the mount, he "passed over a ridge of trapean conglomerate, with embedded quartz pebbles." Again, on September 26th, he records more hills of the "trapean conglomerate." "The rock," he says, "consists of a base of common felspar, with embedded grains of quartz, giving to some parts the character of a conglomerate, and there are also embedded crystals of common felspar."

(b) Mr. E. J. Dunn, who knew this district very well, says, in his book on "Pebbles," page 47: "At Mount Greenock (Vic.) the auriferous tertiary lead was broken through by a volcanic outburst, and the crater of Mount Greenock formed over its former course . . . The pebbles became entangled in the flow of basalt." Again, on page 63: "Where volcanoes break through conglomerates, pebbles may become entangled with the lava flows, and by this means be transported to some fresh site; an instance of this occurs at Mt. Greenock."

While this simple explanation may be the true one, there is no definite proof that such is the case. Indeed, there are some reasons for doubting that this would fully account for the presence and mode of occurrence of the quartz.

IV.—Distribution, etc., of the Quartz.

In the Mt. Greenock flow, as far as it has been examined, over an area of about two square miles, the distribution of the quartz through the rock is by no means uniform. While there are places, such as Walker's Cliffs (A in map), the schoolyard (B in map), and others, where the quartz is so abundant that the basalt resembles a conglomerate, yet in other places it is sometimes only possible to find one small crystal to an ordinary hand specimen, and in other places it is still more rare.

The size of the quartz fragments is very variable, and in shape much irregularity is also shown. Nothing that could be definitely called rounded or even sub-angular occurs.

The large amount of quartz that must be present in the whole flow, and its distribution through the same, although not uniform, seems to debar the possibility of its having been picked up at the crater as the lava came through originally; further, from the mode of flow of a lava stream it is just as difficult to imagine how the quartz could be picked up from the floor of the valley, and distributed through the flow. The lack of any "pebble" form, and the extent of chemical interaction with the magma also seem to militate against this supposition.

Some of the instances from England, South Africa, etc., which have been investigated, and recorded, are apparently very similar to this case, and for none of these was such an explanation advanced. J. Cosmo Newbery, in a catalogue of Victorian rocks, published in 1894, says: "Quartz occurs in the newer basalt of Baringhup, Maldon, frequently in grains and irregular patches of bluish-white colour, and in such association with the rock as to leave no doubt of its original formation in it."

V.—General description of the Lava.

The volcanic products of Mount Greenock may be roughly described under three heads:—

(a) Scoriaceous material; the mount is almost wholly composed of this fragmentary rock, bombs are common, while ropy structure and surfaces showing "flow" lines are of striking freshness.

(b) The lower ledges of the mount show outcrops of extremely dense compact basalt, very fine grained.

(c) The remainder of the flow, extending as a sheet southward, and locally known as part of Nicholl's plains, is of a less fine-grained type, often with a coarse doleritic texture, occasionally vesicular, and generally resembling the material so common in the road metal quarries of Ballarat or Melbourne.

The general characters of these three types are set out below, especially with reference to the quartz content as seen in the hand specimen, and under the microscope.

(a) The quartz in the scoria is generally very small in size; the largest seen formed the centre of a small bomb, and was about $\frac{5}{8}$ in. in greatest length. Crystals of $\frac{1}{8}$ in. diameter are common, and in a section cut where only one small piece of quartz was visible to the eye, a dozen were revealed by the microscope. The scoria contains abundant tiny idiomorphic felspars, a good deal of irregular-shaped augite, and some olivine, with abundant glass. No sign of reaction rims could be detected around the microscopic quartz grains, although the shapes suggested that corrosion had taken place. Hyalite is common, lining cavities in the scoria.

(b) The second type of basalt hardly appears to contain any quartz. Under the microscope the rock consists of a ground-mass of glass and oxides of iron, packed with tiny acicular felspars, and dotted with porphyritic olivine. There is very little augite present, which is rather a contrast to the third type of rock, where augite is common. The most definite augite present in this dense type consists of the tiny green pyroxenic needles forming the reaction rim around one of the rare pieces of contained quartz.

(c) This third type is that of the main flow. As stated, the appearance in hand specimen is quite similar to that of the great majority of the Victorian newer basalts, except that in places throughout the mass it is thickly mottled with corroded quartz. In addition, quartz fragments occur sparsely right throughout the flow. These are quite uncommon as microscopic pieces, but range from $\frac{1}{8}$ in. diameter up to $\frac{3}{4}$ in., and even larger, one mass seen being 14 inches in diameter.

In the hand specimen the quartz shows a great amount of fracturing, and is sometimes surrounded by a minutely vesicular discontinuous border. It very frequently has a peculiar chalcedonic lustre, but is mostly dull-grey in colour. Where the quartz is most abundant, hyalite occurs, and was always noted on the roofs of the containing cavities (Fig. 2).

Under the microscope the rock is of a coarse doleritic texture, with large felspar laths, interspersed with granular augite, and abundant porphyritic olivine. Apatite is present, in bunches of needle-like crystals, and iron oxides occur throughout. "Contraction vesicles" are also common.

Where the quartz comes into contact with the other minerals of the rock, there is always a reaction rim of pyroxenic material, with sometimes a thin band of glass separating it from the quartz. This border is sometimes granular, darkened apparently by the presence of iron oxides; at other times the pyroxene prisms are parallel, roughly normal to the edge of the quartz, presenting under crossed nicols a very pretty appearance. Fig. 3 shows these typical relations diagrammatically.

The quartz shows abundant inclusions, running in lines through the mineral, and negative crystals were observed. The larger pieces of quartz are not single crystals. Along many of the fractures, seams of brown glass occur. In shape the quartz is irregular, and embayed, and cavities occasionally occur in it, lined by a rim of pyroxene.

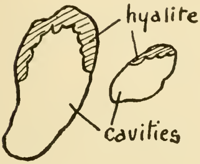

Fig 2.

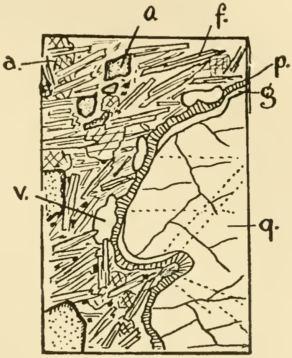

Fig. 3.

Fig. 2. Sketch of hyalite as it occurs on the top of the cavities.

Fig. 3. Diagrammatic representation of the general relations of the quartz to the basalt, as seen under the microscope—q., quartz; g., glassy border; p., pyroxenic rim; v., part of vesicular border; o., olivine; a, augite; f., felspar.

VI.—Other occurrences in Victoria.

A fact worthy of note in connection with these occurrences is that, in the area within 30 miles of Ballarat, where basalt is generally abundant, an investigator who is trying to find fragments of quartz in the basalt rarely fails to do so. Certainly no extreme cases have been found, such as those at Mt. Greenock, nor have any been found with the wonderfully abundant and uniform distribution recorded by Diller and Iddings. A list of localities in Victoria, where pieces of quartz have been found in the basalt, follows :—

Baringhup, J. Cosmo Newbery, Des. Cat. Vic. Rocks, 1894.
Mt. Franklin, Selwyn. Catalog. Vic. Rocks, 1868.
Gleeson's Hill, Selwyn. Catalog. Vic. Rocks, 1868.
Kilmore, with hyalite, Selwyn. Catalog. Vic. Rocks, 1868.
Skipton, near the basalt caves at Mt. Widderin, 1914.
Ballan, near the railway station, 1914.
Lake Burrumbeet, north and east shores, 1914.
Piggoreet, in the "Devil's Kitchen," 1914.

Warrion Hills, in scoria, 1914.
Warrenheip, in scoria, 1914.
Flow above Pike's dam, at Ballan, 1915.
Near new Moorabool dam, Ballarat, 1915.
Mount Elephant, in scoria, 1915.

VII.—World-wide occurrence.

The occurrence of quartz in basalt and allied basic rocks is world-wide, and a large amount of literature exists concerning the same. "Quartz basalt" as a rock type appears to be generally recognised, and in such cases as those of North America, described by Diller, Iddings, and others, it seems impossible to doubt that "the quartz is just as much a primary constituent of the rock as is the olivine." Daly gives the total area covered by quartz basalts in North America as eight square miles. The occurrence mentioned in this paper can only be claimed, at most, as a "quartziferous basalt"—analogous to some of the recorded occurrences of South Africa, Scotland, etc. Daly, in "Igneous Rocks and Their Origin," records quartz basalts "or their allies" from practically every corner of the earth—from Antarctica to Greenland.

VIII.—Literature.

Books and articles that have been consulted include :—

(a) "A late volcanic eruption in Northern California, and its peculiar lava." J. S. Diller Bull. 79, U.S. Geol. Survey, 1891.
(b) "The occurrence of primary quartz in certain basalts." J. P. Iddings, Bull. 66, U.S. Geol. Survey, 1890.
(c) "Igneous Rocks and Their Origin," R. A. Daly, 1914.
(d) A.J.S., Art. XX. J. P. Iddings, 1888.
(e) "Tertiary Igneous Rocks of Skye." A. Harker. chap. XX., etc., 1904.
(f) Intrusions of Kilsyth, Croydon district, Scotland. G. W. Tyrell, Geol. Mag., 1909.
(g) Q.J.G.S. J. W. Judd, pp. 175-186, May, 1889.
(h) Lamprophyres of N. England. Geol. Mag., pp. 109-206. A. Harker, 1892.
(i) Porphyritic quartz in basic igneous rocks, p. 485. A. Harker, 1892.
(k) Petrology for Students. A. Harker, 1897 edn., pp. 138, 190.

(l) Natural History of Igneous Rocks, p. 322. A. Harker.
(m) Data of Geo-chemistry. F. W. Clarke, 1911.
(n) Petrology of the Kalgoorlie Goldfield. J. A. Thomson. Geol. Mag., Vol. LXIX., 1913.
(o) Geology of Kalgoorlie. C. O. G. Larcombe. Proc. Aust. I.M.E., Vol. V., No. II.

IX.—Final considerations.

The efforts to account for the presence of quartz in basic igneous rocks have been many :—

1. Iddings believes that at great depths, and under the mineralising influence of water, in the case of great pressures, quartz could crystallise out from a basic magma, and while in most cases the quartz would later be entirely resorbed, the quartz basalts represent cases where the resorption is incomplete. This theory, while it would satisfactorily explain most features of the case, takes us deep into the region of practically unknown physical properties and processes. Iddings suggests that the occurrence of free quartz in basic rocks is analogous with the occurrence of iron-olivine in acid rocks.

2. Daly suggests, in accordance with his theory of a fundamental basalt magma, from which all igneous rocks are derived—that the quartz found in basalts represents part of the overlying lighter siliceous layer caught up and not fully assimilated by the basalt. This fascinating generalisation would easily lend itself to an explanation of all quartz in basic rocks, but from its fundamental nature it is a question the discussion of which must be left to expert petrologists.

3. The most common explanation advanced is that the quartz is derived from acid rocks through which the basalt has passed on its way to the surface.

As far as is known, the country rock at Mt. Greenock is wholly Ordovician sediments; these are all fine grained, and contain no beds from which the quartz could be derived. If the latter mineral came from the very numerous quartz veins that traverse the ordovician sediments—and from its microscopic nature this is quite possible—we should also expect some fragments of the slates themselves to be still undigested. Close search has failed to reveal any trace of a slate inclusion, a fact which seems sufficient to invalidate that theory.

4. It is also suggested that the quartz was picked up by the lava at the surface.

Some reasons have already been advanced to show that this might not answer in the case of the Mount Greenock occurrence. The chief points were—(a) The difficulty of forming a mental picture of any means whereby the quartz could be "picked up" by a viscous stream, which is really not "flowing" in the same sense as water flows; (b) the extent of the chemical inter-action between the quartz and the containing rock.

As stated by Diller, in his discussion of this matter, all quartz grains in a basic lava, whether native or foreign at the time of its effusion, "would be subjected to the same conditions, all would be corroded by the magma, and each have its re-action rim of pyroxene formed." Still, the amount of inter-action must be largely dependent on the heat of the magma at the time the quartz was "picked up." Clarke, in his Data of Geo.-chemistry, p. 282, gives the temperature of emerging lavas as "rarely if ever below 1000 deg. C., while the actual temperature not long before emission may be hundreds, perhaps 1000, degrees higher." The most reliable data as to the fusion point of quartz give its transformation to tridymite at 800 deg. C., and subsequent fusion at about 1625 deg. C. Geikie records that "lava from Terre del Greco fused the sharp edges of flints."

In the occurrences under discussion, however, the amount of corrosion has been very great, the embayed quartz in some cases showing traces of having been originally twice as large. In the scoria, as has been described, the only minerals showing corrosion are the quartz, and the olivine, suggesting that both these minerals were in the molten material before ejection.

Efforts were made, in the assay laboratory at the Ballarat School of Mines, to reproduce the supposed conditions of "picked up" quartz. Some normal basalt was melted, quartz was dropped in, and the process of cooling retarded as much as possible. Sections were then cut and microscopically examined. Owing to lack of a proper control over the cooling, the crystallisation was not sufficient to enable any observations of value to be made.

In conclusion, while the Victorian occurrences, as so far investigated, have shown no striking characters, they appear to suggest an intratelluric origin of the quartz, and are of sufficient interest to have some bearing on the still unsettled question of the origin of quartz in basalts. With our hundreds of square miles of basalt still uninvestigated, some facts may yet be brought to light that will have a closer bearing on the problem.